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## PHYSICAL – MECHANICAL PROPERTIES OF ANDESITE – DACITE FIBERS AND THEIR MODIFICATIONS

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The properties of mineral fibers consisting of andesite – dacite, which is an effusive volcanic rock, are studied. The elastic – strength characteristics of elementary fibers, filaments, and also microplastics and plates consisting of unidirectional composites fabricated from filaments and ÉDT-10 epoxy binder are investigated. It is shown that the characteristics of the fibers are quite high and close to the properties of non-alkaline glass and basaltic fibers.

Approximately 3 million metric tons of continuous glass fibers amounting to \$10 – 12 billion are produced yearly in the world. In the form of canvases, roving, ribbons, and fabric is used for fabricating filters, thermal insulation, and oriented glass plastics which are distinguished by high specific strength, chemical stability, and good dielectric properties. Glass fibers are relatively inexpensive, so that they have diverse applications.

As a result of the rapid increase in the production of glass fibers, shortages of raw materials for obtaining glass, first and foremost, sources of boron oxide — boric acid and sodium tetraborate as well as alumina — are appearing. This makes it necessary to search for more readily available and plentiful raw materials, such as natural rock. Analysis of the published literature shows that the manufacturers of continuous mineral fibers use only basalt as a raw material. Basalt is produced in small quantities in Russia and Ukraine. There are no data on the use of other rocks [1 – 3].

In our work we have studied the properties of fibers made of andesite – dacite, which is widely occurring effusive volcanic rock containing more than 50% silica and alumina as well as oxides of iron, calcium and magnesium, and sodium and potassium. Rock compositions suggest that continuous fibers with high elastic – strength properties and good chemical and heat resistance can be produced using high temperatures and optimal cooling rates.

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Test batches of continuous fibers with average diameter 5 – 15 μm have been obtained at the Kamen' i Silikaty JSC (Erevan) in the form of 50 cm long fragments of filaments with linear density 400 and 2000 tex. Fibers extruded from melt of natural andesite – dacite rock (composition A) and from melts containing different additives to lower the temperature of fiber production — soda (composition AS), limestone (composition AI), and soda together with limestone (composition ASI) were studied. The surface of the fibers was not coated with lubricants or dressings during the extrusion process. Similar samples of basaltic and glass fibers were studied for comparison. NRB-13-2500 KV-02 basaltic fibers were fabricated at Kamennyi Vek JSC and RVMPN-10-400-14 (composition S) glass fibers were fabricated at Stekloplastik NPO. In some cases, the indicators attained were compared with those of glass fibers with the composition E.

The strength, elongation, and modulus of elasticity of elementary fibers and filaments as well as the strength of microplastics and unidirectional composites, obtained using filaments and ÉDT-10 epoxy binder, were measured for all compositions studied.

Elementary fibers were drawn from filaments, glued in a 10 mm long frame, the diameter was measured under a microscope, and they were tested for tensile strength using the Shopper hydraulic apparatus with maximum load 100 kgf. In each case, at least 50 samples were tested. This is sufficient to obtain reliable results. To investigate the modulus of elasticity of the elementary fibers, longer samples (50 mm) were

prepared in order to decrease the influence of deformation in the clamps. The testing was performed on the Instron 1122 machine. The $\sigma - \varepsilon$ tensile diagrams were recorded. These diagrams were basically linear and made it possible to calculate the modulus of elasticity $E$, the strength $\sigma$, and the strain $\varepsilon$. Twelve to eighteen samples of each type of fiber were investigated.

Filaments with linear density 400 tex and microplastics based on these filaments were studied under tension on a 100 mm base. First, cladding made up cardboard or glass fiber permeated with 10 epoxy binder was glued on the ends of the samples in order to prevent damage to the fibers in the clamps. The samples with a length of 500 mm were prepared to determine the modulus of elasticity of the filaments. The tests were performed on the Instron 1122 and Reinstein 250 machines.

To fabricate microplastics, fragments of the filaments with linear density 400 tex were drawn manually through a permeation – drawing guide, a load was tied to each one, and they were secured on a special frame which was placed in a furnace at 160°C for 8 h to solidify the binder. To study the properties of composite based on mineral and glass fibers, 8 mm wide and 1.5 – 2.0 mm thick unidirectional plates were made, in addition to microplastics, for compression and bending tests; 3 – 4 mm thick plates were made for shear tests. For this, plaits with linear density 2000 tex were permeated with binder and placed in a sectional metal mold in which the samples were solidified.

The plates were tested using a three-point loading scheme. Ordinarily, failure occurs by a bending mechanism for the ratio $l/h = 6 - 8$ and by a shear mechanism for $l/h = 20 - 30$ or more, where $l$ and $h$ are, respectively, the distance between the supports and the thickness of the sample. The maximum stresses (bending strength $\sigma_b$ and shear strength $\tau_{sh}$) were calculated using the well-known relations [3]

$$\sigma_b = \frac{3}{2}\frac{P_f\, l}{bh^2};$$

$$\tau_{sh} = \frac{3}{4}\frac{P_f}{bh},$$

where $P_f$ is the force rupturing the sample and $b$ and $h$ are, respectively, the width and thickness of the sample.

When bending the plates, the ratio of the load $P$ to the deflection $\varpi$ was recorded. This made it possible to calculate the bending modulus of elasticity as [4]

$$E_b = \frac{1}{4}\frac{P}{\varpi}\frac{1}{b}\left(\frac{L}{h}\right)^3,$$

where $L$ is the distance between the supports.

The compression tests on the plates were performed by the method developed at VIAM. The samples were secured in flat centered clamps, keeping the size of the testing base equal to approximately 3 times the thickness of the plate.

**TABLE 1.**

| Fiber type* | Elementary fiber properties on 10 mm base | | | |
|---|---|---|---|---|
| | $n$ | $d_{av}$, μm | $\sigma_{av}$, GPa | $\nu_\sigma$, % |
| A | 28 | 8.8 | 2.6 | 20.1 |
| | 60 | 5.7 | 3.2 | 21.6 |
| | 53 | 12.2 | 2.8 | 25.0 |
| AS | 119 | 7.3 | 2.6 | 20.5 |
| AI | 57 | 6.1 | 2.9 | 26.8 |
| | 58 | 11.8 | 2.2 | 21.2 |
| ASI | 59 | 6.1 | 2.8 | 21.9 |
| | 60 | 12.6 | 1.4 | 22.8 |
| Basalt | 59 | 13.1 | 3.1 | 19.5 |
| Glass: | | | | |
| E | – | – | 2.2 – 2.7 | – |
| S | 59 | 9.9 | 4.8 | 17.1 |

* The confidence intervals for the average diameter and strength are, respectively, ± 0.1 μm and ± 0.1 GPa.

We now need to discuss the structural characteristics of the composites. The linear density of microplastics based on filaments with density 400 tex was equal to 650 – 700 tex, which corresponds to binder mass of approximately 40 wt.% or 60 vol.%. Similar values are also characteristic for plates whose porosity did not exceed 3%. We were not able to obtain higher fiber content in composites because of the specific features of manual permeation of filaments with a limited length. To calculate the modulus of elasticity and strength of the fibers in microplastics and composites, the failure load was applied to the cross-section of the fibers.

The results of the investigations of elementary fibers on a 10 mm base, specifically, the number $n$ of samples tested, the average diameter $d_{av}$ and the strength $\sigma_{av}$, and the coefficient of variation of the strength $\nu_\sigma$ are presented in Table 1. Examples of the distribution of the diameters and the strength of elementary fibers with compositions A and AS are displayed in Fig. 1. The distribution curves are essentially symmetric. The coefficient of variation of the strength is substantial: $\nu_\sigma = 20 - 30\%$. This can be explained by damage to the fibers when they are extracted from the filaments. Such a variance of the results is also characteristic for the strength of microsamples of glass fibers [5]. In our case, it is exacerbated because of the absence of a lubricant in the filament.

It should be noted that the strength of andesite – dacite fibers A is high and approximately corresponds to the strength of basaltic fibers — 2.8 – 3.5 GPa. It exceeds the strength of composition E glass fibers but it is lower than the strength of composition S fibers. Modification of andesite – dacite with alkaline additives facilitates product and in most cases does not decrease the strength of thin fibers with diameters 6 – 8 μm (for AS, AI, and ASI fibers the strength of the

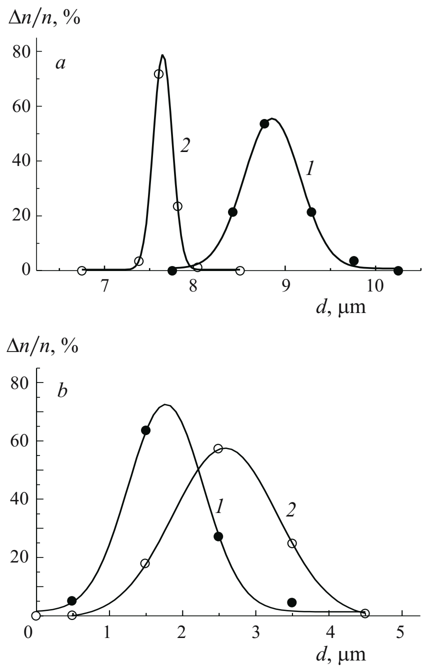


**Fig. 1.** Diameter (*a*) and strength (*b* ) distribution curves for a fibers with compositions A (*1* ) and AS (*2* ).

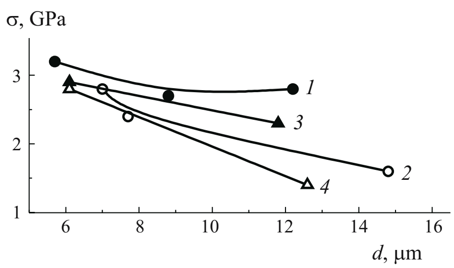


**Fig. 2.** Strength versus diameter of fibers with compositions A (*1* ), AS (*2* ), AI (*3* ), and ASI (*4* ).

elementary fibers is 2.6 – 2.9 GPa). Increasing the diameter of the fibers decreases their strength scale factor. The decrease for fibers with modified compositions is larger (Fig. 2). This is probably due to their suboptimal production conditions.

The properties of elementary fibers tested on a 50 mm base, sufficient for obtaining reliable σ – ε loading diagrams, are presented in Table 2. As an example, Fig. 3 displays several typical diagrams for composition A fibers ($n = 21$). All diagrams are linear up to failure. The modulus of elasticity of andesite – dacite fibers is somewhat larger than for composition E glass fibers but less than for basaltic fibers and composition S glass fibers. The scale effect in the decrease of the strength of fibers with sample length increasing from 10 to 50 mm corresponds to the 20 – 40% (Fig. 4).

The strength of elementary fibers $\sigma_{\text{el.fib}}$ is compared in Table 3 with its computed values, obtained from tests with

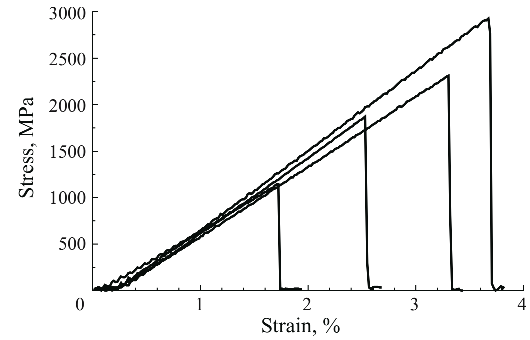


**Fig. 3.** σ – ε load diagrams for composition A fibers with testing on a 50 mm base.

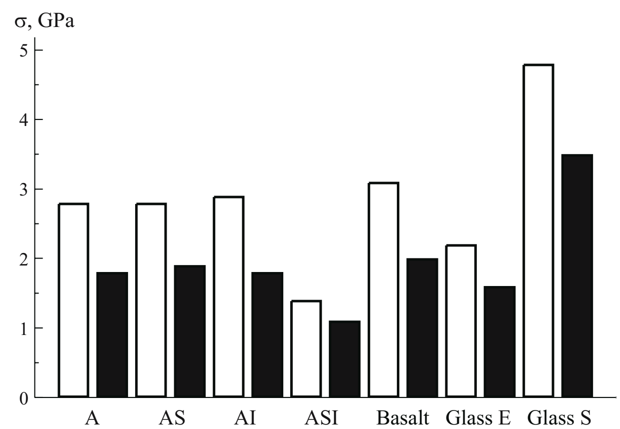


**Fig. 4.** Strength of fibers with different composition with testing on a 10 mm (□) and 50 mm (■) base.

filaments $\sigma_{\text{fil}}$ and microplastics $\sigma_{\text{mc/pl}}$ and the bending strength $\sigma_{\text{c-b}}$ of samples of unidirectional composites. These data are plotted in Fig. 5. It is evident that a good correlation is observed only between the strength of elementary fibers and their strength in microplastics and composites. It is expressed to a lesser extent between the strength of a filament and elementary fibers and is completely absent for the pa-

**TABLE 2.**

| Fiber type* | Elementary fiber properties on a 50 mm base | | | | | | |
|---|---|---|---|---|---|---|---|
| | $n$ | $E$, GPa | $\nu_E$, % | $\sigma_{av}$, GPa | $\nu_\sigma$, % | ε, % | $\nu_\varepsilon$, % |
| A | 21 | 74.6 | 6.9 | 1.81 | 7.4 | 2.6 | 6.7 |
| AS | 19 | 73.1 | 6.7 | 1.93 | 4.7 | 2.7 | 4.1 |
| AI | 20 | 75.5 | 4.8 | 1.77 | 7.2 | 2.6 | 6.6 |
| ASI | 19 | 74.9 | 2.8 | 1.10 | 3.2 | 1.6 | 1.9 |
| Basalt | 20 | 80.4 | 5.7 | 2.00 | 6.4 | 2.6 | 6.5 |
| Glass: | | | | | | | |
| E | – | 72.0 | – | – | – | – | – |
| S | 20 | 95.0 | 2.9 | 3.52 | 3.7 | 3.8 | 4.1 |

* Fiber diameter 7 – 14 μm.

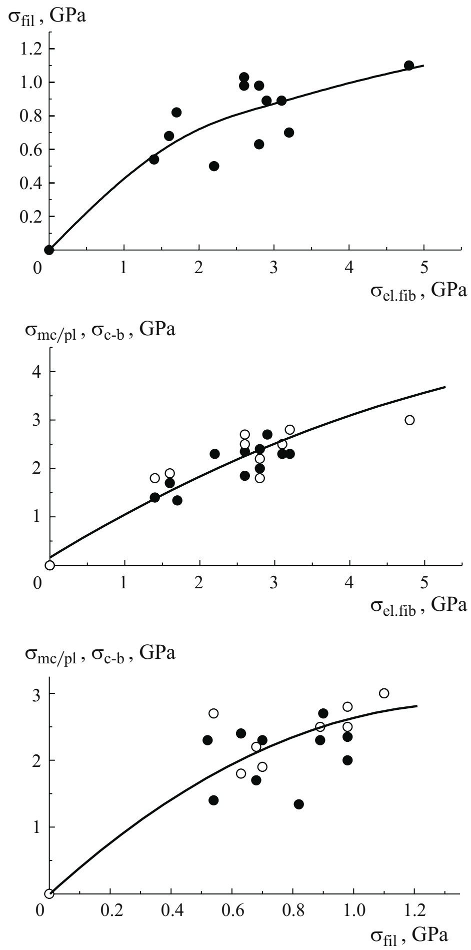


**Fig. 5.** Correlation between the strength of the elementary fibers $\sigma_{el.fib}$, filaments $\sigma_{fil}$, microplastics $\sigma_{mc/pl}$ (●), and unidirectional composites under bending $\sigma_{c\text{-}b}$ (○).

rameters $\sigma_{mc/pl} - \sigma_{fil}$. The low strength of mineral and glass fibers and filaments is explained by their different lengths, contact stresses in the clamps, and dynamical effects with failure of individual components. The strength of fibers in microplastics and composites approximately corresponds to the strength of elementary fibers on a 10 mm base.

**TABLE 3.**

| Fiber type | Typical strength values, GPa | | | |
|---|---|---|---|---|
| | $\sigma_{el.fib}$ ($l$ = 10 mm) | $\sigma_{fil}$ ($l$ = 100 mm) | $\sigma_{mc/pl}$ ($l$ = 100 mm) | $\sigma_{c\text{-}b}$ |
| A | 3.2 | 0.70 | 2.30 | 2.5 |
| AS | 2.6 | 1.03 | 1.85 | 1.8 |
| AI | 2.9 | 0.89 | 2.70 | 3.0 |
| ASI | 2.8 | 0.98 | 2.00 | 2.5 |
| Basalt | 3.1 | 0.89 | 2.30 | 2.8 |
| Glass: | | | | |
| E | 2.2 – 2.7 | 2.80 – 3.00 | 2.50 | – |
| S | 4.8 | 1.10 | 3.00 | 2.7 |

**TABLE 4.**

| Fiber type* | Typical values of the modulus of elasticity, GPa | | | |
|---|---|---|---|---|
| | $E_{el.fib}$ | $E_{fil}$ | $E_{mc/pl}$ | $E_{c\text{-}b}$ |
| A | 72 | 69 | 70 | 62 |
| AS | 76 | 62 | 62 | 65 |
| AI | 75 | 64 | 61 | 61 |
| ASI | 73 | 61 | 62 | 58 |
| Basalt | 82 | 68 | 63 | 68 |
| Glass: | | | | |
| E | 72 | – | – | – |
| S | 95 | 88 | 83 | 89 |

* $E_{el.fib}$ with $l$ = 50 mm, $E_{fil}$ with $l$ = 450 mm, $E_{mc/pl}$ with $l$ = 100 mm, $E_{c\text{-}b}$ with $l/h$ = 30.

**TABLE 5.**

| Fiber type | Composite-sample characteristics | | | | |
|---|---|---|---|---|---|
| | $V_{fib}$, % | $E_b/E_{V60}$, GPa* | $\sigma_b/\sigma_{V60}$, GPa* | $\sigma_c/\sigma_{V60}$, GPa* | $\tau_{sh}$, MPa |
| A | 52.0 | 29.1/33.6 | 0.98/1.13 | 0.41/0.47 | 52 |
| AS | 48.0 | 23.5/29.4 | 0.89/1.11 | 0.44/0.55 | 41 |
| AI | 41.0 | 28.0/30.9 | 1.10/1.60 | 0.45/0.56 | 49 |
| ASI | 45.3 | 24.0/31.8 | 0.95/1.61 | 0.35/0.60 | 39 |
| Basalt | 49.0 | 29.4/40.8 | 1.34/1.64 | 0.40/0.49 | 54 |
| Glass: | | | | | |
| E | – | – | – | – | – |
| S | 44.0 | 34.8/47.4 | 1.24/1.69 | 0.45/0.98 | 56 |

* Computed values.

The values of the modulus of elasticity for samples of elementary fibers, filaments, microplastics, and fibers in unidirectional composites tested under bending are given in Table 4. Evidently, the modulus of elasticity of the elementary andesite fibers is equal to the modulus of elasticity of composition E glass fibers and equals 72 – 75 GPa, and is lower than the value for basaltic and glass (composition S) fibers. In filaments, microplastics, and for bending of plates consisting of composites, the modulus is somewhat lower, probably because of the nonuniform distribution of stresses and strains during testing of these samples.

The characteristics of composites in the form of 1.5 – 3.5 mm thick plates are presented in Table 5: the volume content of fibers $V_{fib}$, the modulus of elasticity $E_b$, the bending strength $\sigma_b$, the compression strength $\sigma_c$, and the shear strength $\tau_{sh}$. Together with the measured values, the computed values referenced to a single volume content of the fibers, specifically, $V_{fib}$ = 60%, are also indicated. The elastic strength properties obtained for composites show that it may

be possible to use such composites extensively in different structures.

These investigations have shown that the characteristics of materials based on andesite – dacite fibers are quite high. They are somewhat lower than the characteristics of basalt and glass plastics, but the results show that these indicators become comparable when the fiber-drawing process is improved, commercial vessels are used, and production is round-the-clock. Apparently, the shear strength can also reach an optimal level characteristic for composites based on basaltic and glass fibers.

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